Application of Taguchi - L9 Orthogonal Array Method for Optimization of Turning Operation on Lathe

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Abstract- *Machining operations have been the core of the manufacturing industry since the industrial revolution. Productivity and quality are two important characteristics that control most of the manufacturing processes. Material Removal Rate (MMR) imposes one of the most significant constraints for the selection of cutting parameters and machine tools in development of a process. The optimized parameters of machining are important specially to maximize production rate and to reduce cost. In actual practice, all the factors which affect the surface roughness are classified into tool variables, work piece variables and cutting conditions. To this end, a great deal of research has been performed in order to quantify the effect of various turning process parameters to MMR. In present work, an attempt is made to optimization of MMR in turning operations using Taguchi method, which is being applied successfully in industrial applications for optimal selection of process variables in the area of machining.*

Keywords: *Machining Parameters, Minitab 19, Optimization Techniques, Taguchi Method, Turning Operation.*

I. INTRODUCTION

In today's competitive environment they need for optimal use of resources like CNC machines is an important issue. Cutting parameters such as speed, feed, depth of cut, affect the production rate, quality, and cost of the component, during a machining operation. Turning is a versatile and useful machining operation. It is the most important operation and is widely used in most of the manufacturing industries due to its capability of producing complex geometric surfaces with reasonable accuracy and surface finish. In modern industry one of the trends is to manufacture low-cost, high-quality products in a short time. Increasing productivity, decreasing costs, and maintaining high product quality at the same time are the main challenges manufacturing faces today. [1]

Process optimization is the discipline of adjusting a process to optimize some specified set of parameters without violating some constraint. The most common goals are minimizing cost, maximizing throughput, and/or efficiency. This is one of the major quantitative tools in industrial decision making. Manufacturing industries have long depended on the skill and experience of shop-floor machine tool operators for optimal selection of cutting conditions and cutting tools. The most adverse effect of such a not very scientific practice is decreased productivity due to suboptimal use of machining capability. Optimization of machining parameters not only increases the utility for machining economics but also the product quality to a great extent. In conventional (manual) manufacturing systems, the machined components take only about 6%to 10% of the total available production time on machines being used. By contrast, it has been estimated that the percentage would increase to 65%-80% in modern computer-based manufacturing because of the advent of computer-based and automated machining systems. This situation makes the need for economic optimization and reliable performance data of machining processes even more pressing than ever before. The surface roughness greatly varies with the change of cutting process parameters. Surface finish in turning is influenced in varying amounts by many factors such as feed rate, work material characteristics, work hardness, unstable built-up edge, cutting speed, depth of cut, cutting time, tool nose radius and tool cutting edge angles, the stability of machine tool and workpiece setup, chatter, and use of cutting fluids.[2]

1.1 Turning Process

Turning is the primary process in most of the production activities in the industry. In the turning process, a single-point cutting tool moves along the axis of a rotating workpiece. Turning is used to reduce the diameter of the workpiece, usually to a specified dimension, and to produce a smooth finish on the metal. Turning produces rotational, typically axisymmetric parts that have many features, such as holes, grooves, threads, tapers, various diameter steps, and even contoured surfaces.

It can be done manually, in a traditional form of lathe, which frequently requires continuous supervision by the operator, or by using a computer-controlled and automated lathe which does not. Parts that are fabricated completely through turning often include components that are used in limited quantities, perhaps for prototypes, such as custom-designed shafts and fasteners. Turning is a form of machining or a material removal process that is used to create rotational parts by cutting away unwanted material as shown in Figure 1. The turning process requires a turning machine or lathe, workpiece, fixture, and cutting tool. The workpiece is a piece of re-shaped material that is secured to the fixture, which itself is attached to the turning machine, and allowed to rotate at high speeds. The cutter is typically a single-point cutting tool that is also secured in the machine. The cutting tool feeds into the rotating workpiece and cuts away material in the form of small chips to create the desired shape.

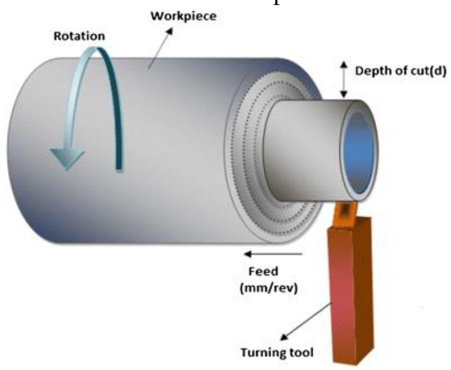

Figure 1. Systematic view of Turning Operation

In turn, the speed and motion of the cutting tool are specified through several parameters. These parameters are selected for each operation based upon the workpiece material, tool material, tool size, and more. Turning parameters that can affect the processes are:

a. Cutting speed -The speed of the workpiece surface relative to the edge of the cutting tool during a cut, measured in surface feet per minute (SFM).
b. Spindle speed -The rotational speed of the spindle and the workpiece in revolutions per minute (RPM). The spindle speed is equal to the cutting speed divided by the circumference of the workpiece where the cut is being made. To maintain a constant cutting speed, the spindle speed must vary based on the diameter of the cut. If the spindle speed is held constant, then the cutting speed will vary.
c. Feed rate -The speed of the cutting tool's movement relative to the workpiece as the tool cuts. The feed rate is measured in mm per revolution.
d. Depth of Cut -The depth of the tool along the radius of the workpiece as it cuts, as in a turning or boring operation. A large depth of cut will require a low feed rate, or else it will result in a high load on the tool and reduce the tool life. Therefore, a feature is often machined in several steps as the tool moves over at the depth of the cut.

1.2 Taguchi method

Taguchi method is an efficient problem-solving tool for the design of experiments when many process parameters are involved in the process. This technique reduces significantly experimental time and cost and also improves the performance of the process, system, design, and product. Taguchi approach is suitable in experimental design for designing and developing robust products or processes irrespective of variation in process parameters (within set limits) or variation in environmental conditions. For analysis of the entire process parameters Taguchi method generally employs specially designed orthogonal arrays with a small number of experiments. This method uses the signal to noise ratio for measuring the deviation of the quality characteristic from the desired value because ‘signal’ represents the desirable value namely the mean for the output characteristics and ‘noise’ represents the undesirable value or standard deviation for the output characteristics. The L9 orthogonal array has been used for this study. The methodology used to achieve optimized process parameters using Taguchi is as given below:

1. To select the influencing process parameters with their levels and perform the trial turning as per the Taguchi method, then collect data.
2. To analyze the data using statistical tools. Taguchi method can be obtained to determine the statistical significance of the parameters. Means plots can be plotted to determine the preferred levels of parameters considered for experimentation.
3. Select optimum levels of control parameters, perform confirmation experiments, and implement the process

II. LITERATURE REVIEW

Many researchers have contributed a lot to the optimization of machining parameters. J.S pang et.al. [3] introduces the application of Taguchi optimization methodology in optimizing the cutting parameters of the end milling process for machining the halloysite nanotubes (HNTs) with aluminum reinforced epoxy hybrid composite material under dry condition. Vijay.S and Krishnaraj V. [4] optimizes the machining parameter like cutting speed, feed and depth of cut for minimizing the cutting forces induced during machining and to reduce the surface roughness of the machined parts. Alakesh Manna and Sandeep Salodkar [5] describes the procedure to obtain the machining conditions for turning operation considering the unit cost of production as an objective function. The optimality conditions for single-point cutting operations are determined based on the objective function using the dynamic programming technique. Cakirand Gurada [6] considered the minimum production cast as the objective function to describe a procedure for evaluating the machining conditions during milling operations. Juan et.al. [7] developed an optimization algorithm using a simulated annealing method for minimizing producing cost during rough milling. Shunmugam et.al [8] optimized the machining parameters such as depth of cut in each pass, speed, and feed using the genetic algorithm to yield the minimum total production cost during face milling operations. Stockton and Wang [9] developed an advanced modeling technique using an artificial neural network and verified the developed cost model with the standard cost model for a turning process.

Increase in productivity is desired during the machining processes which depend upon Material Removal Rate (MRR). Higher the MRR more the productivity achieved, Cost of machining is strongly related to the MRR. MRR for a turning operation is given by product of cutting parameters (speed, feed and depth of cut). Thus, it is very essential to study MRR. Sayak Mukherjee et.al formulated an experiment using Taguchi to optimize MRR during turning of SAE1020 using mixed ceramic insert. The experiments resulted with a maximum MRR at optimum cutting parameters and showed that depth of cut has the most significant effect on MRR.[10] R. K. Suresh et.al investigated the effect of cutting parameters on EN-41 B alloy steel using Taguchi technique. An accurate regression model is developed for material removal rate. They found that feed is the most dominant parameter for MRR.[11] Vijaykumar S. Jattiet.al developed an empirical model to predict material removal rate in terms of spindle speed, feed rate and depth of cut using multiple regressions modelling method. AlMgSiCu was workpiece material and carbide inserted cutting tool. For material removal rate, confirmation experiments resulted in an average percentage error of 3.35, underlining the satisfactory performance of the prediction model.[12]

III. EXPERIMENTAL SETUP DETAILS

3.1 Lathe Machine Selection

The lathe is a very versatile and important machine to know how to operate. This machine rotates a cylindrical object against a tool that the individual controls. The lathe is the forerunner of all machine tools. The work is held and rotated on its axis while the cutting tool is advanced along the line of the desired cut. The lathe is one of the most versatile machine tools used in the industry. With suitable attachments, the lather may be used for turning, tapering, form turning, screw cutting, facing, dulling, boring, spinning, grinding, polishing operations.

Figure 2. Selected Lathe

3.2 Cutting Tool Selection

The tool is a single-point cutting tool made of High-Speed Steel. The new tool is purchased for experiment purposes, MIRANDA TOOLS HSS Single Swastik M2 Square Tool Bit Blank, 1/2 x 4-inch. The available Size of a single-point cutting tool having a dimension in detail are Length - 4\" | Width - 1/2\" | ZEDD: M2 (HSS with 0% Cobalt) (62-65 HRc). High-speed steel provides a balance of hardness for wear resistance and toughness for shock resistance. It also has features like Superior Quality, Better Performance, More Durability. The ends are beveled at 15 degrees and ready for machining to a custom tool bit shape.

Table 1. Cutting Tool Details

Brand Name	MIRANDA TOOLS
Colour	Grey
Item Weight	0.45 grams
Manufacturer Series Number	M2TB1/2X4
Material	High-Speed Steel
Model Number	DB-EETT-1WQ1
Part Number	M2TB1/2X4
Shank Type	Square
Size	Standard

3.3 Workpiece Material Selection

EN24T steel is a popular grade of through-hardening alloy steel due to its excellent machinability in the "T" condition. EN24T is used in components such as gears, shafts, studs, and bolts, its hardness is in the range 248/302 HB. EN24T can be further surface-hardened to create components with enhanced wear resistance by induction or nitriding processing. EN24 is usually supplied in the T condition with a tensile strength of 850/1000 N/mm$^{2.}$

3.3.1 Application

EN24T steel is high tensile alloy steel renowned for its wear resistance properties and also where high strength properties are required. EN24T is used in components subject to high stress and with a large cross-section. This can include aircraft, automotive, and general engineering applications for example propeller or gear shafts, connecting rods, aircraft landing gear components.

Table 2. Composition of EN24T

C	**SI**	**MN**	**S**	**P**	**Cr**	**Mo**	**Ni**
0.36/ 0.44	0.10/ 0.35	0.45/ 0.70	0.040 max	0.035 max	1.00/ 1.40	0.20/ 0.35	1.30/ 1.70

Table 3. EN24T Steel Mechanical Properties

Size mm	Tensile Strength N/mm²	Yield Stress N/mm²	Elongation	Impact Izod J	Hardness HB
63 to 150	850-1000	680 Min	13%	54	248/302
150 to 250	850-1000	654 Min	13%	40	248/302

Heat uniformly to 823/850°C until heated through and oil quenched to complete the process of hardening. Then **tempering is done by applying heat** uniformly and thoroughly at the selected tempering temperature, up to 660°C, and hold at heat for two hours per inch of the total thickness. **Stress-relieving takes place by providing** heat slowly to 650-670°C, soak well. Cool the EN24 tool in a furnace or air.

Material Removal Rate (MRR) Measurement From the initial and final weight of the job MRR is calculated and the relation is given below:

MRR = (Initial Wt -Final Wt)/Time Taken

3.4 Parameter Selection

Three parameters Cutting speed, feed rate, and Depth of cut with three levels as shown in Table 4. are taken under consideration in drilling as the process parameters

3.4.1 Spindle Speed

Spindle speed refers to the rotating speed of the work piece. It was increased from 250 rpm to 500 rpm. The depth of cut was kept between 0.5 mm – 1.5 mm throughout the process, but the feed rate was varied from 0.18 mm/rev to 0.32 mm/rev, with a single turning operation for each feed rate.

3.4.2 Feed Rate

The feed rate is the rate at which the tool advances along its cutting path. It was increased from 0.18 mm/rev to 0.32 mm/rev, by keeping the depth of cut constant at 0.5mm throughout and varying speed from 250 rpm to 500 rpm with a single turning operation for each speed.

3.4.3 Depth of Cut

It is the total amount of metal removed per pass of the cutting tool. It is expressed in mm. It can vary and depend upon the type of tool and work material. The depth of cut was kept between 0.5 mm – 1.5 mm with the constant perpendicular feed of 0.05 mm concerning the parallel feed of range between 0.18 mm/rev to 0.32 mm/rev.

Table 4. Process Parameters

Level	Spindle Speed (rpm)	Depth of Cut (mm)	Feed Rate (mm/Rev)
1	250	0.5	0.18
2	355	1.0	0.24
3	500	1.5	0.32

IV. Design of Experiment

Taguchi's designs aimed to allow a greater understanding of variation than did many of the traditional designs. Taguchi contended that conventional sampling is inadequate here as there is no way of obtaining a random sample of future conditions. Taguchi proposed extending each experiment with an "outer array" or orthogonal array should simulate the random environment in which the experiment would function.

Table 5. Taguchi L-9 Orthogonal Array Result

Experiment No.	Spindle Speed (rpm)	Depth of Cut (mm)	Feed Rate (mm/rev)
1	250	0.5	0.18
2	250	1	0.24
3	250	1.5	0.32
4	355	1	0.18
5	355	1.5	0.24
6	355	0.5	0.32
7	500	1.5	0.18
8	500	0.5	0.24
9	500	1	0.32

The whole experimentation is divided into different phase. In first phase After doing initial turning on workpiece the diameter is reduced to 50 mm. Workpiece is cut into equal part of length 60 mm and measured initial weight of all jobs. As per the defined conditions there are three machining parameters i.e., Spindle speed, Feed rate, Depth of cut. Different experiments are done by varying one parameter and keeping other two fixed so maximum value of each parameter was obtained. Operating range is found by experimenting with top spindle speed and taking the lower levels of other parameters. A combination of all three parameters is found beyond which tool or job fails.

Experiments are performed according to the selected design of experiment as shown in Table. Machining time is noted by stopwatch and measured final weight of all jobs. Material removal rate (MRR) is calculated by using relation
MRR = (Initial Wt – Final Wt)/ Machining Time.
In the first run nine experiments are performed and material removal rate (MRR) is calculated. The observations are shown in Table no. 6.

Table 6. Observation of First Run

Spindle Speed (rpm)	Depth of Cut (mm)	Feed Rate (mm/rev)	Time (sec)	Initial Weight (g)	Final Weight (g)	MMR (g/sec)
250	0.5	0.18	17	747	703	2.60
250	1	0.24	14	767	691	5.41
250	1.5	0.32	12.6	772	653	9.48
355	1	0.18	9.6	772	716	5.83
355	1.5	0.24	8	768	697	8.82
355	0.5	0.32	8.56	794	770	2.84
500	1.5	0.18	7.5	763	697	8.78
00	0.5	0.24	7.5	768	746	2.99
500	1	0.32	6.4	737	699	5.88

V. RESULTS

Taguchi method stresses the importance of studying the response variation using the signal–to–noise (S/N) ratio, resulting in minimization of quality characteristic variation due to uncontrollable parameter. The metal removal rate was considered as the quality characteristic with the concept of "the larger-the-better".

$$S/N = -10 \log_{10}\left\{\frac{1}{n}\sum \frac{1}{y^2}\right\} \quad (1)$$

Where n is the number of measurements in a trial/row, in this case, n=1 and y are the measured value in a run/row. The S/N ratio values are calculated by taking into consideration Eqn. 1 with the help of software Minitab 19. The MRR values measured from the experiments and their corresponding S/N ratio values are shown in Table 7.

After finding all the observation as given in Table 8 and 9, S/N ratio and Means are calculated and various graph for analysis is drawn by using Minitab 19 software. The S/N ratio for MRR is calculated on Minitab 19 Software using Taguchi Method.

Table 7. Taguchi Analysis Result

Spindle Speed	Depth of Cut	Feed Rate	MMR	S/N Ratio	MEAN
250	0,5	0,18	2.60	8.29947	2.6
250	1,0	0,24	5.41	14.6639	5.41
250	1,5	0,32	9.48	19.5362	9.48
355	0,5	0,24	5.83	15.3134	5.83
355	1,0	0,32	8.82	18.9094	8.82
355	1,5	0,18	2.84	9.06637	2.84
500	0,5	0,32	8.78	18.8699	8.78
500	1,0	0,18	2.99	9.51342	2.99
500	1,5	0,24	5.88	15.3875	5.88

5.1 Taguchi Analysis MMR versus Spindle Speed, Depth of Cut, Feed Rate

In this study, Spindle Speed, Depth of Cut, Feed Rate are considered as the main characteristic. The MINITAB®19 software is used to analysis, in order to assess the influence of factors on the response, the mean and the Signal-to-noise ratio for each control factor are calculated and represented in table 4. The decisive factor - 'lager is better' is used for choosing the S/N ratio. The response table for means and S/N ratio are shown in the Tables 8 and 9.

Table 8. Response Table for Signal to Noise Ratios

Level	Spindle Speed	Depth of Cut	Feed Rate
1	14.167	14.161	8.96
2	14.43	14.362	15.122
3	14.59	14.663	19.105
Delta	0.424	0.502	10.145
Rank	3	2	1

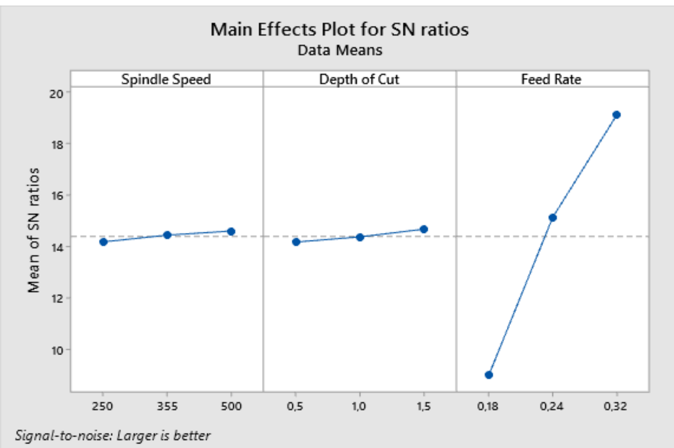

Figure 3. Effect of Turning Parameters on Material Removal Rate for S/N Ration

Table 9. Response Table for Means

Level	Spindle Speed	Depth of Cut	Feed Rate
1	5.83	5.737	2.81
2	5.83	5.74	5.707
3	5.883	6.067	9.027
Delta	0.053	0.33	6.217
Rank	3	2	1

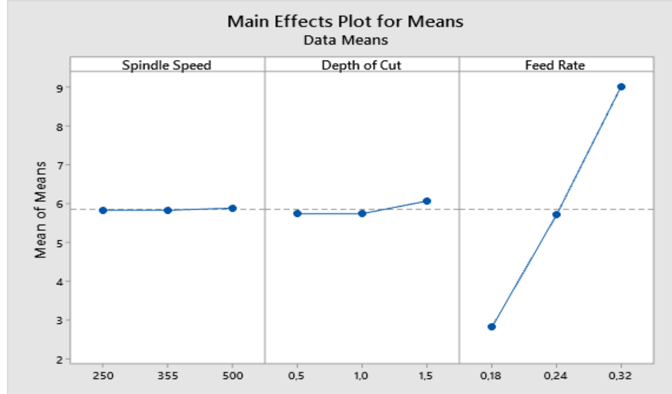

Figure 4. Effect of Turning Parameters on Material Removal Rate for Mean Values

a. **Spindle Speed:** The effect of parameters spindle speed on the metal removal rate values is shown above figure 3 for S/N ratio. Its effect is increasing with increase in spindle speed up to 500 RPM. So, the optimum spindle speed is level 3 i.e., 500 RPM

b. **Depth of Cut:** The effect of parameters depth of cut on the metal removal rate values is shown in figure 3 for S/N ratio. So, the optimum depth of cut is level 3 i.e., 1.5 mm.

c. **Feed Rate:** The effect of parameters feed rate on the metal removal rate values is shown below in figure 3, for S/N ratio. Its effect is increasing with increase in feed rate. So, the optimum feed rate is level 3 i.e., 0.320 mm/rev.

Regardless of the category of the performance characteristics, a greater S/N value corresponds to a better performance. Therefore, the optimal level of the machining parameters is the level with the greatest value. The experiment is conducted according to table no.6 from graphs, it is seen that optimization values are speed (500), depth of cut (1.5) and feed (0.320) and above result are cross verified by conducting the same experiment and it found the same result.

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